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Performance of Instantaneous Gas-Fired Water Heaters

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Building Environment Division
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Final Report

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

Four different instantaneous, gas-fired water heaters were tested to develop a test method to determine recovery efficiency (Er) and energy factor (EF). All four of the water heaters were from foreign countries (West Germany, the United Kingdom, France and Japan). Various flow rates and water draws were used during the tests to determine their influence on the recovery efficiency and energy factor. In addition, the pilot light power consumption was measured to determine the effect of a variable pilot light power rate on the energy factor. The use of recovery efficiency as a performance index seems appropriate for these units, however, the use of energy factor, as presently calculated, needs further study.

DISCLAIMER

This report is intended to provide the baseline for the development of test procedures for instantaneous water heaters and not to judge the performance of the water heaters for any specific application. Although the units tested were not identified by manufacturer, inclusion of a given unit in this report in no case implies a recommendation or endorsement by the National Bureau of Standards, and the presentation should not be construed as a certification that any unit would provide the indicated performance. Similarly, the omission of a unit does not imply that its capabilities are more or less than those of the included units.

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NOMENCLATURE

Cc	Daily hot water energy consumption (Btu/day)
Cf	Correction factor to convert measured gas to Standard Cubic Feet (SCF) (dimensionless)
Cwh	Daily water heating energy consumption (Btu/day)
Cy	Average daily energy consumption, derived from cold tank recovery test (Btu/day)
Er	Recovery efficiency (dimensionless)
EF	Energy factor, the ratio of daily hot water energy consumption to the daily energy consumption with a particular water heater (dimensionless)
Fr	Flow rate of water (gallons per minute)
H	Higher heating value of gas (Btu/SCF)
k	Specific heat of water (8.25 Btu/(gallon - °F))
P	Power used by water heater (Btu/hour)
Pa	Atmospheric pressure in inches of mercury (Note: if the pressure is in Millibars, then multiply by 0.02953 to convert to inches Hg)
Pg	Gas pressure (inches Hg) note: to convert inches of water to inches Hg, multiplied by 0.07343)
Pr	Pilot light energy consumption rate (Btu/hr)
Pwv	Water vapor pressure, partial (inches Hg)
Q	Heat supplied to water heater during a test (Btu)
R	Recovery rate (gallons/hour)
Ta	Ambient air temperature (°F)
Tcp	Combustion products temperature in the stack (°F)
Td	Time of draw (minutes)
Tg	Temperature of the natural gas at the gas meter (°F)
Th	Hot water temperature during a draw (°F)
Tha	Average hot water temperature during a draw (°F)

Ti	Inlet (supply) water temperature (°F)
Tia	Average inlet (supply) water temperature (°F)
U	The nominal daily hot water usage
Vol	The measured volume of gas used during a test (cubic feet)
Ww	Weight of water drawn (pounds)

1. INTRODUCTION

Four different instantaneous, gas-fired water heaters were tested to develop a test method to determine the recovery efficiency, Er, and energy factor, EF, for these units. Although thermal efficiency and standby loss tests have been defined by the American Gas Association and published as ANSI Standards [1,2]*, the tests were not prepared in the contex of an integrated, overall energy conservation program for water heaters. These water heater types have been called by a number of other descriptive names: i.e. in-line, tankless, demand, point of use, geyser and instantaneous. In this report, the designation "instantaneous" will be used. These water heaters are of interest for their potential to save energy since they should have lower standby losses, perhaps higher recovery efficiencies and energy factors than storage type gas-fired water heaters currently in use.

1.1 Objective

The objectives of these tests were: (1) to establish a baseline for the development of an appropriate test method for instantaneous water heaters; (2) to characterize the performance of instantaneous, gas-fired water heaters; (3) to use the test data to determine a method of calculating a recovery efficiency, Er, and energy factor, EF, for instantaneous water heaters; (4) to judge the adequacy of using these

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* Note: Numbers in brackets refer to references at the end of the report.

factors to rate instantaneous water heaters and; (5) to assess the suitability of these factors in comparing the performance of instantaneous water heaters to storage type water heaters.

1.2 Theory of Operation

Instantaneous water heaters provide hot water on demand. Because these are tankless heaters, they avoid some of the standby losses, namely flue and jacket losses, usually associated with storage type units. Most of the currently produced units have integral controls to modulate the firing rate of the main burner as a function of water flow rate or outlet water temperature although some of the older units have fixed firing rate burners. In addition, most units have some minimum flow to activate (turn-on) the main burner. The main burner also is provided with the usual proof-of-flame sensor device along with high temperature and other safety features required for automatic, gas-fired appliances.

Units which incorporate flow sensor devices are activated by variable water flow rates to modulate the gas flow rate to the main burner. These units generally have a knob on the control panel to provide a convenient means to manually set the regulated temperature rise of the hot water. Turning this knob adjusts the flow sensor control mechanism which controls main burner modulation. Other heaters use a thermal sensing bulb filled with an expandable fluid that expands and contracts in response to the temperature changes of the water in the finned-tube heat exchanger. The expanding fluid actuates a bellows that increases the opening of the main burner gas control valve to modulate the burner firing rate to control the hot water temperature within a certain

range. This second type is a thermostatically modulated control whereas the first type is a flow modulated control.

As the flow rate of the hot water is increased, the firing rate of the main burner is increased to maintain the hot water discharge temperature at or near the particular temperature set point. Further increases in flow rates of the hot water beyond that corresponding to the maximum firing rate will result in a corresponding decrease in the hot water temperature as the flow rate is above the range of modulation. In all types of instantaneous gas-fired water heaters, a cessation of hot water flow extinguishes the main burner.

All of the units have pilot lights which are started by manually operating a push button to activate a piezoelectric spark igniter. The pilot light remains activated enabling it to ignite the main burner as often as required to satisfy any subsequent hot water draws. Pilot lights may be manually extinguished to save energy if hot water usage is not anticipated for an extended time.

1.3 Potential Applications

In domestic household applications, instantaneous water heaters may be installed:

(1) In a central location, as a replacement for a storage type water heater in typical use in the U.S. In this application, some standby losses may be reduced since there is no stored hot water and no associated jacket losses.

(2) In series with a separately fired hot water storage tank, where the hot water is stored in the tank at a reduced temperature. When hot water is drawn, the instantaneous water heater serves as a booster heater to increase the water temperature to some higher value. Energy may be saved from reduced standby losses of the storage tank because of the lower temperature of the stored water.

(3) Locally at selected hot water usage points where each instantaneous water heater operates independently. In addition to the reduction of the standby losses by the elimination of jacket and flue losses, there may be reduced piping heat losses since pipe runs to the point of use would generally be shorter.

(4) In conjunction with an insulated storage tank with a circulating pump and suitable controls allowing the system to function as a indirect-fired storage type water heater. In this configuration, flue losses may be reduced as a contributor to the standby losses and it is possible that the recovery efficiency may be higher than that of conventional gas-fired storage water heaters because of the use of finned tube heat exchangers. Also, instantaneous water heaters with reduced firing rates might be used if the hot water were stored in an insulated storage tank. Some efficiencies gained may be offset, however, because of the required water circulating pump and controls.

2. SCOPE AND TEST PROCEDURES

2.1 Scope

Four (4) instantaneous natural gas-fired water heaters were tested. They all vary in water heating capability and all are manufactured

overseas namely: West Germany, Great Britain, France, and Japan. It should be emphasized that the testing conducted on these units were not meant to evaluate the units themselves but rather to aid in the development of meaningful test procedures on a generic basis for all instantaneous type water heaters.

2.2 Test Setup and Laboratory Conditions

The test setup for instantaneous gas-fired water heater testing is shown in Figure 1. Units were designated F, G, H, and I (letters A through E were used for tests of other types of water heaters not reported herein) and each unit tested separately through the manual setting or control of the appropriate gas and water valves. The testing setup also allowed the required instrumentation to be used efficiently with a minimum of change or modification.

The supply water temperature was conditioned to the desired temperature (normally 70°F**) in the conditioning tanks and circulated by a pump to ensure that the inlet supply water to the instantaneous heaters was of a uniform temperature during testing. Appropriate valves were set so that the domestic supply water pressure was used to pressurize the water system to force the flow of water as required by the hot water

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** Note: In this report inch-pound units are generally used to be consistent with DOE and other published test procedures although some temperature data were collected in degrees Celsius. An S/I conversion table is included in Appendix B.

draws. Water flow rates were set by control valves and the flow rate was monitored by a flow meter.

The total volume of water drawn during the test was measured by using a 120 gallon collecting tank mounted on a balance beam scale. The balance beam was fitted with an electrical switch which controlled a valve on the supply water inlet to the instantaneous water heater being tested. After water flow was initiated, the outlet hot water coming from the instantaneous water heater was collected in the 120 gallon tank, the weight of the incoming water gradually leveled the balance beam. When a predetermined weight representing the total water volume to be drawn was reached, the electrical switch on the balance beam was activated. This stopped the supply water flow to the water heater and ended the test. The actual flow rate was calculated by timing and weighing the total water flow.

During certain tests, a portable combustion efficiency analyzer was used to determine combustion efficiency. This measurement was to be compared later to the calculated water heater efficiency for correlation.

Tests were conducted at a laboratory ambient temperature of approximately 70°F. All water heaters were tested with draw tests since the burner is activated only by a draw. A traditional recovery test [3] which draws no water was not a suitable type of test for an instantaneous type water heater. Although this type of water heater

has no storage tank, a recovery efficiency was calculated for each test (see Section 4, Test Results and Calculations). The pilot light gas consumption rate was measured for all water heaters tested.

2.3 Measurements Taken

The following measurements were taken and recorded for each test.

1. Ambient air temperature, Ta
2. Natural gas inlet temperature, Tg
3. Inlet (supply) water temperature, Ti
4. Outlet (hot) water temperature, Th
5. Stack (combustion products) temperature, Tcp
6. Amount of hot water drawn during a test (in pounds), Ww
7. Time of draw (in minutes, used to accurately measure flow rate), Td
8. Barometric air pressure (in milli-bars and converted to inches of mercury), Pa
9. Higher heating value of natural gas and converted to Btu per SCF, H
10. Inlet (supply) natural gas pressure measured in inches of water column and converted to inches of mercury, Pg
11. Quantity of natural gas used in cubic feet and converted to standard cubic feet, Vol.

2.4 Test Procedures

In general, the following procedures were followed for the testing of each instantaneous gas-fired water heater:

1. Water in the conditioning tanks was prepared for use as the inlet (supply) water for the instantaneous heater test by heating or cooling, as needed, to bring the supply water to the desired starting temperature.
2. The drain valve on the 120 gallon water collecting tank was opened to ensure that the tank was empty. The valve was then closed and the balance beam was set to activate the switch so as to stop the flow of supply water after the required weight of hot water was collected from the instantaneous water heater being tested.
3. Water control valves were set to provide domestic water line pressure to the supply tanks.
4. The water heater to be tested was isolated by turning off the cold water supply valves to all other water heaters. The appropriate gas valves were set to assure that only the water heater to be tested had natural gas supplied, then, the pilot light was ignited by following the specific instructions for the particular water heater.
5. The datalogger was set to record the necessary thermocouple measurements (input supply water temperature, outlet hot water temperature, and ambient air temperature) at one minute intervals.
6. The natural gas meter and the barometric pressure were read.
7. The test was initiated by opening the water inlet valve to the instantaneous water heater using the flow meter to set the nominal test flow rate. Simultaneously, the datalogger and timer were started.
8. While a draw was being made and the water heater burner was activated, the natural gas pressure and the portable combustion

efficiency analyzer were read. The portable combustion efficiency analyzer which measures combustion products and temperatures was used only for a selected number of tests.

9. When the draw was complete the scale beam tipped to cause the cold water supply control valve to close and terminate the water flow. The elapsed time since the start of the draw was recorded as well as the natural gas meter reading.

10. The tank drain valve was then opened to empty the 120 gallon collecting tank, and the datalogger reset to prepare for the next test.

3. TEST DATA

A number of tests were conducted on each of the four instantaneous water heaters. The test data are shown in Tables 1a, 1b, 1c, and 1d for Units F, G, H, and I, respectively. Each tested unit is shown along with an identifying test number and each test series is identified by sequential test numbers. The higher heating value of the gas, H, is the same for all the tests conducted within the series.

As can be observed, the hot water flow rates were varied from approximately 1 gallon per minute (GPM) to approximately 3 GPM although several tests were conducted at a hot water flow rate of approximately 4 GPM for Unit H. For each test, the total amount of hot water drawn is also indicated, varying from 5 gallons to 50 gallons. Most tests, however, were conducted using a total volume of 21.4 gallons which corresponds to the first draw volume of the proposed simulated use test for storage type water heaters [4]. The simulated use test for storage

type water heaters is conducted by drawing a total of 64.3 gallons in three equal draws of 21.4 gallons each.

The measured inlet and outlet temperature, in degrees Celsius, is also shown in Tables 1a through 1d along with the correction factor, Cf, used to convert measured gas to "standard" cubic feet, SCF; the cubic feet of gas used during the test, CuFt; and the higher heating value for the gas used, H. The measured pilot light energy consumption for each unit is also indicated along with the corresponding hourly BTU rate.

For convenience, the inlet and outlet water temperatures as well as the outlet minus inlet water temperature, T1, are also shown in degrees Fahrenheit. Finally, the Btu content of the gas, Q, used for each test is calculated as the product of (Cf)(Vol)(H) and indicated in Tables 1a through 1d.

4. TEST RESULTS AND CALCULATIONS

4.1 Water Flow Rate Versus Temperature Rise

In order to characterize each of the tested units regarding its ability to provide hot water, the data shown indicating flow rate, GPM, and temperature rise, T1, from Tables 1a through 1d were plotted. The results for Units F, G, H and I are shown in Figures 2, 3, 4, and 5, respectively. For each graph, the results for the 21.4 total draw test series are generally connected by lines for clarity. In addition, the total gallons of water drawn for each test is indicated.

For Unit F, the draw rates varied from approximately one to three GPM as shown in Figure 2. As can be seen, the congruency of the GPM versus Temperature Rise lines are rather scattered and some of the data points at draw rates of approximately 1 GPM, for a total draw of 5 and 10 gallons, are somewhat anomalous. The predominant GPM versus Temperature Rise trend is approximately linear from about a temperature rise of 68°F at 1 GPM to 45°F at 3 GPM as represented by two of the draws from the 21.4 gallon series tests and the 15 gallon draw tests. The third 21.4 gallon series plot is offset from the others. Note that Unit F cannot provide hot water at a temperature rise of 77°F which represents water heated from an inlet temperature of 58°F to an outlet temperature of 135°F. It does, however, provide hot water above a temperature rise of 55°F at 2 GPM. This temperature rise represents hot water at 113°F if the inlet water is 58°F; which is a water temperature considered useful for most domestic hot water uses.

The GPM versus Temperature Rise characterization for Unit G is shown in Figure 3. In this case, the GPM versus Temperature Rise lines are fairly congruent and linear from a temperature rise of approximately 85°F at 1.7 GPM to a temperature rise of 47°F at 3.2 GPM. These lines represent hot water draws of 5 gallons, 21.4 gallons, and 50 gallons. As can be seen, Unit G is capable of producing hot water at a temperature rise of 77°F, again, representing the heating of water from an inlet temperature of 58°F to an outlet temperature of 135°F at a flow rate of approximately 1.9 GPM. For Unit G, the range from 1 GPM and 1.7 GPM represents main burner modulation range at these lower flow

rates. These points are rather scattered and tend toward a higher temperature rise with an increase in flow rate, as might be expected within this flow rate range.

Unit H exhibits the trend in GPM versus Temperature Rise characteristics as shown in Figure 4. From a temperature rise of approximately 86°F at 1 GPM to a temperature rise of approximately 45°F at 4 GPM, the trend appears somewhat uniform with the exception of the 7.5 gallon data points. In addition, the lines exhibit little similarity within the overall range. This unit will deliver hot water at a temperature rise of 77°F with a flow rate of approximately 1.7 GPM.

Unit I, the unit with the highest firing rate in Btu/hr input of the four units tested also exhibited a somewhat linear characteristic with reasonable similarities from a temperature rise of approximately 89°F at 2.2 GPM to a temperature rise of approximately 69°F at 3 GPM, if the single 81°F temperature rise at 3 GPM data point is not included (see Figure 5). Data points at flow rates less than approximately 2.2 GPM represent the unit operating within the range of modulation. This unit provides the highest flow hot water rate of approximately 2.6 GPM at a temperature rise of 77°F of the four units tested. It should be noted that Unit I was not operated at its maximum output due to gas line supply restrictions.

4.2 Calculation of Recovery Efficiency

Using the test data shown in Tables 1a through 1d a Recovery Efficiency, Er, was calculated for each test using the equations in Appendix A. These calculated Er's are shown in Tables 2a through 2d along with the individual values used for the calculation. It should be noted that the Er calculation is based on the active operation of the instantaneous water heater for the actual water volume heated and the actual temperature rise achieved during the test. The water volume is not normalized to any particular volume and the fuel consumed by the pilot light is ignored during the water heater's quiescent period (the time in which the pilot alone is burning and no water is being drawn). The Er for the four units tested varied from approximately 0.72 to 0.90.

The Er for each unit tested was plotted as a function of water flow rate and is shown in Figures 6, 7, 8, and 9, for Units F, G, H, and I, respectively. As can be seen, the lines connecting the points which represent each test series are not congruent. However, the aggregate of the points plotted indicate a general trend showing a higher Er with increased flow rate with an increase in Er ranging from approximately 0.05 to 0.1 between the draw rates of 1 GPM and 3 GPM. The Er for Units F, G, and H all seem to lie nominally between 0.75 and 0.85 while Unit I shows a nominal Er range from 0.80 to 0.90.

Generally, the Er appears to be somewhat sensitive to the flow rate and the temperature rise used for the calculation, as represented by the

differences of the plotted lines and the small increase in Er at the higher flow rates.

4.3 Portable Combustion Efficiency Analyzer Results

A portable combustion efficiency analyzer was used during several tests conducted on Unit H in order to determine if there was any correlation between the calculated Er and the combustion efficiency. The combustion efficiency analyzer measures the flue gases and analyzes the combustion products and temperatures. A comparison of the combustion efficiencies displayed by the analyzer and the calculated Er for tests 22 through 28 for Unit H is as follows:

Test	Combustion Efficiency	Calculated Recovery Efficiency (Er)
H22	.779	.783
H23	.775	.797
H24	.754	.739
H25	.766	.766
H26	.794/.787	.798
H27	.789/.780	.786
H28	.791/.787	.801

The two combustion efficiency values for tests 26H, 27H, and 28H are given because the analyzer showed two different readings during course of the tests; the second readings were taken about 30 seconds after the first readings. The analyzer updated its reading once each second. As can be noted, the values for the two methods used to determine Er compare rather closely.

4.4 Calculation of Energy Factor

Energy Factors, EF, were also calculated for each test using the equations in Appendix A. The calculated EF's are shown in Tables 2a through 2d. The EF is based on a 24 hour simulated use test and

assumes that a total number of gallons of heated water is drawn at a specified flow rate. It further assumes that during the 24 hour simulated use test, the pilot light of the instantaneous water heater is burning while no water is drawn. The EF is calculated as the ratio of the energy content of a day's supply of hot water divided by the total energy required to provide the hot water plus the energy used by the pilot light during the time hot water is not being drawn.

The EF's calculated for each test for an assumed number of different daily water usages are shown in Tables 2a through 2d. The energy consumption of the pilot light for each unit is also shown. It should be noted that these calculations are determined from the actual test data to reflect the EF for the total daily water usages of 20, 40, 64.3, and 80 gallons.

The EF's for each test as a function of water flow rate for Units F, G, H, and I are shown in Figures 6, 7, 8, and 9 respectively, along with the plots for Er versus Flow Rate shown in these figures. For clarity, data for a total flow (U) of 64.3 gallons are not shown since the curves would tend to overlap with the data shown for total water drawn for 40 and 80 gallons. The 64.3 gallon data, however, if plotted would fall between the 40 and 80 gallon plots and have the same general shape as the 40 and 80 gallon plots.

All of the EF curves for each of the units tested generally follow the same trends. As can be observed, the greater the total amount of water drawn, the higher the EF. This follows from the fact that the EF is

calculated over a 24 hour period and the larger the hot water draw the shorter the standby time. It is the energy consumed during this standby time that has a very measurable effect on the EF. As the standby time is decreased by a longer water draw, the EF approaches the Er. The limiting case is when water is drawn continuously for a 24 hour period and there is no standby time when only the pilot light is burning.

It should also be noted that generally the higher the flow rate for a given total draw, the lower is the resulting EF. This is related to the standby time of the instantaneous water heater. If the amount of water to be drawn is removed at a greater flow rate, the recovery time is shortened increasing the standby time and lowering the EF, assuming a constant burning pilot during the standby period.

The Energy Factor is also a function of the pilot light energy consumption rate. The pilot light energy consumption rates for the various units are as follows:

Unit F	340 Btu/hr
Unit G	357 Btu/hr
Unit H	643 Btu/hr
Unit I	896 Btu/hr

Generally, the higher the pilot light energy consumption rate, the lower the EF for a given Er. For example, the Units with the smallest pilot light energy consumption rates (Units F and G) have Energy Factors of approximately 0.42 for a total hot water draw of 20 gallons at 3 GPM. For the same conditions, Unit H with a pilot light consumption rate of 643 Btu/hr has an EF of approximately 0.35 and

Unit I, with a pilot light consumption rate of 896 Btu/hr has an EF of approximately 0.32.

Finally, it should be noted that the EF's shown in Figure 6, 7, 8, and 9 vary in congruency and are sensitive to varying degrees to the parameters which are used for the EF calculations. Also, the EF's that show a positive slope derive this slope by following the positive modulating range slope shown for the GPM versus Temperature Rise plots for each Unit.

5. DISCUSSION

5.1 Determination of Unit GPM at a Temperature Rise of 77°F

In viewing the graphs of Er and EF with their multiple points as shown in Figures 6, 7, 8, and 9, one might question which of these points represents the Er and EF for the four instantaneous water heaters tested. Since the basis for these factors originate from the points found on the GPM versus Temperature Rise curves shown in Figures 2, 3, 4, and 5, a method for selecting a single point is desirable.

For consistency of comparison, it is advantageous to conduct all water heater tests under the same test conditions. Toward that end, the units should be tested at a flow rate of 3 GPM at a temperature rise of 77°F with 135°F outlet water, the same conditions recommended for testing all residential water heaters [4]. If that temperature rise at that flow rate cannot be achieved, then the highest flow rate obtainable by the unit which produces a temperature rise of 77°F should

be used. Units G, H, and I can heat water to a temperature rise of 77°F, at lower flow rates than 3 GPM. Unit F could not achieve a temperature rise of 77°F at any flow rate (see Figure 2).

Because of the incongruity of the GPM versus Temperature Rise curves crossing the 77°F temperature rise line, it appears that a single draw test would be inappropriate. The testing of instantaneous water heaters should use a number of draws and temperature rises and be run often enough to characterize the performance of the particular water heater under test. One way of accomplishing this would be by drawing 20 gallons of water at a temperature rise of 80°F, 77°F, and 75°F, defined as a draw series, and repeating these draws for a total of three series. This would represent a total of 9 water draws of 20 gallons each. The measured GPM versus Temperature Rise can then be plotted on a graph and the series lines connected. If the intersection of the series lines with the 77°F constant temperature rise line (see Figures 2 through 5) is observed to have a GPM spread of 0.2 GPM or less, the average of the three intersections should be used as the GPM output of the instantaneous water heater at a temperature rise of 77°F.

If the spread is greater than 0.2 GPM, repeat the tests for 3 additional series totaling an additional 9 draws of 21.4 gallons each. These additional measured GPM versus Temperature Rise points are added to the original graph, then the lines are connected and the intersections of the six lines crossing the constant temperature rise line of 77°F averaged. The average of these points would represent the

GPM output of the instantaneous water heater at a temperature rise of 77°F.

5.2 Determination of Recovery Efficiency

The single flow rate required to provide a water temperature rise of 77°F should be used to calculate the Er for the water heater. Since the Er as a function of flow rate is fairly constant (see Figure 6, 7, 8, and 9), errors in GPM versus Temperature Rise measurement or inconsistent unit operation due to burner firing tolerances should have little effect on the resulting Er. This procedure should be modified if, for any reason, other units tested exhibit characteristics that are significantly different from these four tested units.

The comparison of Er's between instantaneous water heaters seems to be a reasonable index of relative performance. This is true even though the maximum flow rate at a temperature rise of 77°F varies among water heaters. Since the Er, as a function of flow rate, is fairly constant, the calculated values should not be significantly affected.

Instantaneous water heaters that do not have the ability to deliver water at a temperature rise of 77°F cannot be compared by this index of performance. With regard to the index itself, it is doubtful that a Er for instantaneous water heaters can be directly compared to a Er for storage type water heaters with any meaning. One difference is that the instantaneous water heater will generally supply less than the 3 GPM flow rate as is used for storage type heaters. Another is that once the flow rate at a temperature rise of 77°F for an instantaneous

water heater is determined, it can produce this flow of hot water indefinitely. This area of comparison needs further investigation and study.

5.3 Determination of Energy Factor

Once a flow rate at a temperature rise of 77°F is determined, the EF for the unit can be determined given a total daily draw of hot water and the pilot energy consumption rate. Although the EF is somewhat sensitive to flow rate, it seems adequate to determine this index at the, single, representative flow rate at the flow rate output of 77°F as described in 4.1. However, the Energy Factor is sensitive to the total water drawn and the pilot light energy consumption rate.

An argument could be made that since instantaneous water heaters are designed to deliver an unlimited supply of hot water at a given temperature rise and flow rate, any index for these units which is based on a specific total water delivery may be misleading. For example, the less water that is used, the lower the EF; although the Er remains the same. And this decrease in Energy Factor is not caused by the operation of the unit but rather by the effects of the energy used by the pilot light.

Another consideration in using the EF as a performance index is that the units are designed to be turned-off, that is, the pilot light is extinguished when the unit is not in use. The pilot lights, however, are easily started by manually operating a push button to activate a piezoelectric spark igniter. Although this mode of operation is common

overseas, such operation has been basically untested as a viable mode of operation by individuals in the United States who have been conditioned to not having to activate their pilot lights on their storage type water heaters. In considering a performance index, it is questionable as to whether or not the water heater should be penalized by assuming that the user will not make full use of the built-in energy saving potential associated with this type of water heater. As for the pilot energy consumption rate, the point is moot if the pilot light is turned off after each use. This area also requires additional investigation and study to determine its usefulness as a performance index for instantaneous water heaters and as a common denominator to compare the performance of storage type water heaters.

6. CONCLUSIONS

Based on an analysis of the data for the tests conducted on four instantaneous water heaters, the following general conclusions are submitted:

1. The actual flow rate characteristics at a temperature rise of 77°F for the instantaneous water heaters should be determined by a series of tests.
2. The use of Er as a performance index to compare different instantaneous water heaters seems appropriate.
3. The EF determination for instantaneous water heaters is sensitive to the given total number of gallons drawn, the flow rate, and the pilot light energy consumption rate.

7. REFERENCES

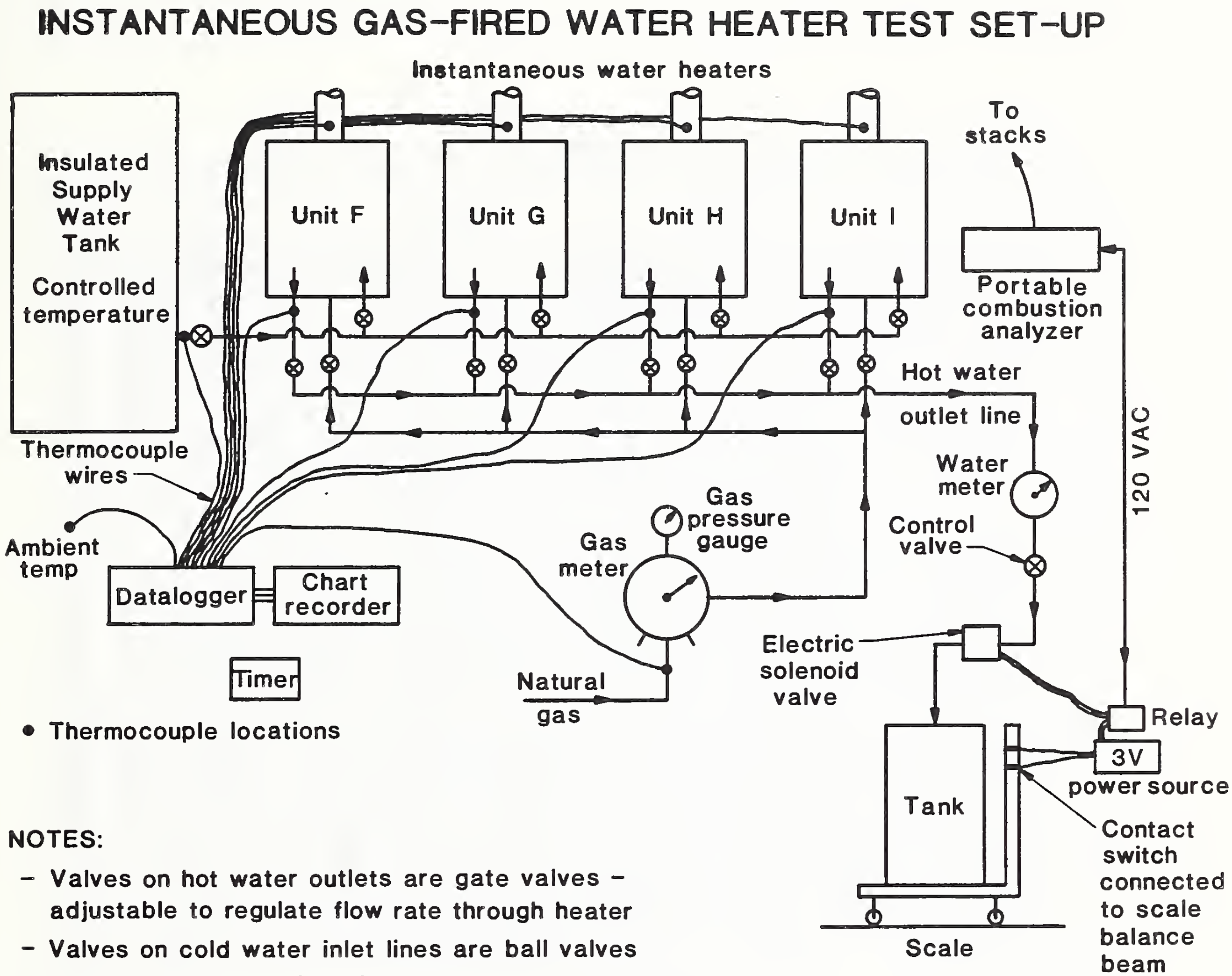
[1] American National Standard for Gas Water Heaters, Volume I-Automatic Storage Water Heaters with Inputs of 75,000 BTU Per Hour or less - ANSI-Z21.10.1-1984.

[2] American National Standard for Gas Water Heaters, Volume III-Circulating Tank, Instantaneous, and Large Automatic Storage Water Heaters - ANSI-Z21.10.3-1984.

[3] Federal Register, Vol. 42, No. 192, October 1977, pages 54200-54119, as amended by Federal Register, Vol. 43, No. 203, October 19, 1978, pages 48986-48987 and Federal Register, Vol. 44, No. 175, September 7, 1979, pages 52632-52640.

[4] Federal Register, Part II, Department of Energy, Office of Conservation and Renewable Energy, 10 CFR part 430, Energy Conservation Program for Water Heaters; Public Hearing; Proposed Rule, pages 4870 - 4889, dated February 8, 1984.

[5] NBSIR 86-3412; DOE/NBS Forum on Testing and Rating Procedures for Consumer Products; October 2-3, 1985; R. D. Dikkers; July 1986.



NOTES:

- Valves on hot water outlets are gate valves – adjustable to regulate flow rate through heater
- Valves on cold water inlet lines are ball valves
- Valve on hot water line after water meter was used to regulate flow rate
- Network of lines and valves allowed quick isolation and start-up of each unit when switching between units (only one heater was tested at a time)
- When balance beam on scale tipped, relay shut solenoid valve to cut off water flow
- Each heater had a pressure-relief valve
- Thermocouple connections on hot water outlets were insulated (immersion-type connections)
- Analyzer was used only on some of the tests – combustion efficiency was calculated by analyzer based on percentage excess air from measured oxygen and stack temperature.

Figure 1. Instantaneous Gas-Fired Water Heater Test Set-Up.

Table 1a. Test Data - Unit F

TEST DATA - UNIT F

UNIT	TEST	‡ FLOW (Gpm)	‡ AMT (Gal)	TIME (Min)	‡ T(C) (Out)	‡ T(C) (In)	T(F) (Out)	T(F) (In)	T(F) (Delta T)	‡ CF	‡ GAS (CuFt)	‡ H (BTU/ CuFt)	Q (BTU)	‡ PILOT (BTU/ Hr)
F	2	2.15	15.0	6.98	52.67	22.40	126.81	72.32	54.486	0.981	8.930	1032	9040.66	340
F	3	2.25	15.0	6.67	51.05	22.33	123.89	72.19	51.696	0.981	8.002	1032	8101.16	340
F	4	2.31	15.0	6.49	50.78	21.95	123.40	71.51	51.894	0.981	7.938	1032	8036.37	340
F	5	1.07	15.0	14.02	57.72	21.11	135.90	70.00	65.898	0.981	10.545	1032	10675.67	340
F	7	1.07	15.0	14.02	58.41	20.67	137.14	69.21	67.932	0.978	10.915	1032	11016.47	340
F	8	3.19	15.0	4.70	45.67	22.15	114.21	71.87	42.336	0.976	6.350	1032	6395.92	340
F	9	3.24	15.0	4.63	46.63	21.74	115.93	71.13	44.802	0.976	6.715	1032	6763.56	340
F	10	1.00	5.0	5.00	44.95	21.38	112.91	70.48	42.426	0.973	2.000	1032	2008.27	340
F	11	3.62	5.0	1.38	45.29	21.17	113.52	70.11	43.416	0.973	2.083	1032	2091.62	340
F	12	3.49	10.0	2.87	45.82	20.91	114.48	69.64	44.838	0.972	4.335	1032	4348.46	340
F	13	3.33	10.0	3.00	46.98	22.26	116.56	72.07	44.496	0.970	4.445	1032	4449.62	340
F	51	0.93	5.0	5.37	63.47	14.41	146.25	57.94	88.308	0.972	4.580	1036	4612.02	340
F	52	0.78	10.0	12.78	62.88	15.01	145.18	59.02	86.166	0.972	9.180	1036	9244.19	340
F	53	0.95	21.4	22.62	57.98	23.37	136.36	74.07	62.298	0.974	14.355	1036	14485.11	340
F	54	1.53	21.4	13.95	54.01	23.23	129.22	73.81	55.404	0.973	12.235	1036	12333.22	340
F	55	1.95	21.4	10.97	52.18	22.50	125.92	72.50	53.424	0.973	11.550	1036	11642.72	340
F	56	2.62	21.4	8.18	48.09	22.05	118.56	71.69	46.872	0.973	9.917	1036	9996.61	340
F	57	3.11	21.4	6.88	45.66	21.78	114.19	71.20	42.984	0.972	9.068	1036	9131.40	340
F	87	0.98	21.4	21.75	59.05	21.44	138.29	70.59	67.698	0.974	16.242	1038	16420.86	340
F	88	1.55	21.4	13.81	55.18	21.08	131.32	69.94	61.380	0.984	14.140	1038	14442.48	340
F	89	2.10	21.4	10.21	51.32	21.45	124.38	70.61	53.766	0.983	12.185	1038	12433.01	340
F	90	2.53	21.4	8.46	48.63	21.18	119.53	70.12	49.410	0.983	10.930	1038	11152.47	340
F	91	3.08	21.4	6.95	46.71	20.29	116.08	68.52	47.556	0.983	10.490	1038	10703.51	340
F	101	1.08	21.4	19.81	57.93	20.93	136.27	69.67	66.600	0.982	15.990	1036	16267.46	340
F	102	1.65	21.4	12.97	54.55	21.15	130.19	70.07	60.120	0.982	13.930	1036	14171.71	340
F	103	2.12	21.4	10.09	52.12	21.32	125.82	70.38	55.440	0.981	12.650	1036	12856.40	340
F	104	2.63	21.4	8.14	48.32	21.46	118.98	70.63	48.348	0.982	10.840	1036	11028.10	340
F	105	2.99	21.4	7.15	46.54	21.66	115.77	70.99	44.784	0.982	10.005	1036	10178.61	340

‡ = Measured Data

Table 1b. Test Data - Unit G

TEST DATA - UNIT G

UNIT	TEST	* FLOW (Gpm)	* AMT (Gal)	TIME (Min)	* T(C) (Out)	* T(C) (In)	T(F) (Out)	T(F) (In)	T(F) (Delta T)	* CF	* GAS (CuFt)	* H (BTU/ CuFt)	Q (BTU)	* PILOT (BTU/ Hr)
G	29	2.22	5.0	2.25	56.96	20.80	134.53	69.44	65.088	0.965	3.432	1035	3427.80	357
G	30	2.11	5.0	2.37	59.92	21.00	139.86	69.80	70.056	0.965	3.617	1035	3612.57	357
G	31	2.07	5.0	2.42	60.24	21.10	140.43	69.98	70.452	0.965	3.670	1035	3665.50	357
G	32	1.63	5.0	3.07	67.48	21.20	153.46	70.16	83.304	0.966	4.383	1035	4382.17	357
G	58	1.01	21.4	21.10	61.49	21.66	142.68	70.99	71.694	0.975	16.060	1036	16222.21	357
G	59	1.65	21.4	12.97	69.00	21.58	156.20	70.84	85.356	0.971	18.180	1036	18288.28	357
G	60	2.10	21.4	10.19	60.44	21.55	140.79	70.79	70.002	0.970	14.850	1036	14923.06	357
G	61	2.53	21.4	8.45	54.11	21.56	129.40	70.81	58.590	0.970	12.355	1036	12415.79	357
G	62	3.16	21.4	6.78	47.36	21.50	117.25	70.70	46.548	0.970	9.815	1036	9863.29	357
G	79	1.06	21.4	20.19	62.87	21.43	145.17	70.57	74.592	0.969	17.270	1033	17286.87	357
G	80	1.65	21.4	12.97	66.91	20.91	152.44	69.64	82.800	0.976	18.442	1033	18593.37	357
G	81	2.10	21.4	10.19	59.79	21.20	139.62	70.16	69.462	0.976	15.315	1033	15440.71	357
G	82	2.68	21.4	7.98	51.56	21.06	124.81	69.91	54.900	0.976	12.425	1033	12526.98	357
G	83	2.68	21.4	7.98	51.18	20.76	124.12	69.37	54.756	0.976	12.375	1033	12476.57	357
G	84	2.66	50.0	18.77	50.88	20.17	123.58	68.31	55.278	0.977	28.990	1033	29257.90	357
G	85	2.63	50.0	18.98	50.64	19.64	123.15	67.35	55.800	0.977	29.205	1033	29474.88	357
G	86	3.02	21.4	7.08	48.87	21.56	119.97	70.81	49.158	0.972	10.970	1038	11068.03	357
G	106	1.06	21.4	20.19	62.56	21.90	144.61	71.42	73.188	0.983	17.205	1036	17521.37	357
G	107	1.35	21.4	15.85	62.05	22.19	143.69	71.94	71.748	0.983	16.590	1036	16895.06	357
G	108	1.63	21.4	13.13	66.94	22.31	152.49	72.16	80.334	0.974	18.255	1036	18420.46	357
G	109	1.87	21.4	11.44	65.97	22.43	150.75	72.37	78.372	0.981	17.330	1036	17612.76	357
G	110	2.08	21.4	10.29	61.57	22.55	142.83	72.59	70.236	0.981	15.620	1036	15874.86	357
G	111	2.64	21.4	8.11	53.33	22.60	127.99	72.68	55.314	0.981	12.290	1036	12490.52	357
G	112	3.16	21.4	6.77	48.63	22.60	119.53	72.68	46.854	0.982	10.295	1036	10473.64	357

* = Measured Data

Table 1c. Test Data - Unit H

TEST DATA - UNIT H

UNIT	TEST	* FLOW (Gpm)	* AMT (Gal)	TIME (Min)	* T(C) (Out)	* T(C) (In)	T(F) (Out)	T(F) (In)	T(F) (Delta T)	* CF	* GAS (CuFt)	* H (BTU/ CuFt)	Q (BTU)	* PILOT (BTU/ Hr)
H	14	1.28	5.0	3.92	67.94	21.50	154.29	70.70	83.592	0.973	4.555	1035	4587.14	643
H	15	1.36	5.0	3.67	67.98	21.50	154.36	70.70	83.664	0.969	4.570	1035	4583.32	643
H	16	3.86	14.2	3.67	47.48	21.50	117.46	70.70	46.764	0.967	6.850	1035	6855.79	643
H	17	3.84	14.1	3.67	47.00	21.40	116.60	70.52	46.080	0.965	6.845	1035	6836.61	643
H	18	1.83	5.0	2.73	64.55	21.38	148.19	70.48	77.706	0.969	4.150	1035	4162.10	643
H	19	1.78	5.0	2.82	64.52	21.40	148.14	70.52	77.616	0.968	4.095	1035	4102.70	643
H	20	4.07	11.3	2.78	45.84	21.42	114.51	70.56	43.956	0.966	5.110	1035	5109.03	643
H	21	3.99	11.1	2.78	46.70	21.40	116.06	70.52	45.540	0.967	5.165	1035	5169.36	643
H	22	2.34	5.0	2.13	60.58	21.78	141.04	71.20	69.840	0.963	3.690	1035	3677.84	643
H	23	2.38	5.0	2.10	60.65	21.73	141.17	71.11	70.065	0.962	3.640	1035	3624.24	643
H	24	1.37	5.0	3.66	67.34	21.69	153.22	71.03	82.181	0.965	4.590	1035	4584.38	643
H	25	1.59	5.0	3.15	65.87	21.57	150.57	70.83	79.740	0.965	4.300	1035	4294.73	643
H	26	3.00	5.0	1.67	52.63	21.38	126.73	70.48	56.250	0.962	2.920	1035	2907.36	643
H	27	2.08	5.0	2.40	62.24	21.24	144.03	70.23	73.800	0.963	3.885	1035	3872.20	643
H	28	3.49	5.0	1.43	48.58	21.08	119.44	69.94	49.500	0.962	2.560	1035	2548.92	643
H	40	2.21	7.5	3.39	58.30	14.49	136.94	58.08	78.858	0.973	6.040	1036	6088.49	643
H	41	2.21	7.5	3.39	57.54	14.59	135.57	58.26	77.310	0.973	5.920	1036	5967.53	643
H	42	1.10	7.5	6.80	57.27	15.21	135.09	59.39	75.701	0.978	6.100	1036	6180.57	643
H	43	1.04	7.5	7.23	60.33	15.88	140.59	60.58	80.010	0.977	6.570	1036	6649.97	643
H	44	1.01	7.5	7.43	61.41	13.36	142.54	56.05	86.490	0.973	7.020	1036	7076.36	643
H	45	1.61	7.5	4.65	61.17	13.78	142.11	56.80	85.302	0.971	6.535	1036	6573.92	643
H	46	2.30	7.5	3.27	60.73	13.11	141.31	55.60	85.716	0.970	6.355	1036	6386.27	643
H	63	1.05	21.4	20.48	68.98	22.26	156.16	72.07	84.096	0.972	19.495	1036	19631.31	643
H	64	1.65	21.4	12.97	62.30	22.14	144.14	71.86	72.283	0.970	16.550	1036	16631.43	643
H	65	2.05	21.4	10.44	61.59	21.64	142.86	70.95	71.910	0.970	15.755	1036	15832.51	643
H	66	2.53	21.4	8.46	57.88	21.60	136.18	70.88	65.304	0.969	14.025	1036	14079.47	643
H	67	3.13	21.4	6.83	52.86	21.46	127.15	70.63	56.520	0.969	11.870	1036	11916.10	643
H	92	1.04	21.4	20.58	71.77	21.25	161.19	70.25	90.936	0.974	21.970	1038	22211.93	643
H	93	1.64	21.4	13.05	66.44	21.34	151.59	70.41	81.180	0.976	18.710	1038	18954.88	643
H	94	2.13	21.4	10.05	62.38	20.80	144.28	69.44	74.844	0.977	16.880	1038	17118.45	643
H	95	2.55	21.4	8.39	58.78	21.09	137.80	69.96	67.842	0.975	15.075	1038	15256.65	643
H	96	3.17	21.4	6.75	52.01	21.28	125.62	70.30	55.314	0.974	12.208	1038	12342.43	643
H	113	1.05	21.4	20.38	71.15	22.61	160.07	72.70	87.372	0.984	20.990	1036	21397.71	643
H	114	1.68	21.4	12.74	65.27	22.60	149.49	72.68	76.806	0.982	17.760	1036	18068.17	643
H	115	1.33	21.4	16.09	68.06	22.59	154.51	72.66	81.846	0.982	19.390	1036	19726.46	643
H	116	2.09	21.0	10.07	63.08	22.10	145.54	71.78	73.764	0.969	17.040	1036	17106.18	643
H	117	2.64	21.4	8.11	57.44	22.31	135.39	72.16	63.234	0.969	14.655	1036	14711.92	643
H	118	3.06	21.4	6.99	53.39	22.50	128.10	72.50	55.602	0.969	12.790	1036	12839.68	643

* = Measured Data

Table 1d. Test Data - Unit I

TEST DATA - UNIT I

UNIT	TEST	* FLOW (Gpm)	* AMT (Gal)	TIME (Min)	* T(C) (Out)	* T(C) (In)	T(F) (Out)	T(F) (In)	T(F) (Delta T)	* CF	* GAS (CuFt)	* H (BTU/ CuFt)	Q (BTU)	* PILOT (BTU/ Hr)
I	33	2.37	10.0	4.22	67.64	21.60	153.75	70.88	82.872	0.974	7.745	1036	7815.20	896
I	34	2.50	10.0	4.00	64.99	21.59	148.98	70.86	78.120	0.974	7.520	1036	7588.16	896
I	35	2.15	10.0	4.65	70.03	21.47	158.05	70.65	87.408	0.974	8.355	1036	8430.73	896
I	36	2.25	10.0	4.44	68.21	21.29	154.78	70.32	84.456	0.974	7.970	1036	8042.24	896
I	37	2.66	10.0	3.77	54.95	12.74	130.91	54.93	75.978	0.974	7.165	1036	7229.94	896
I	38	2.66	10.0	3.76	54.84	13.04	130.71	55.47	75.240	0.974	7.110	1036	7174.45	896
I	39	2.21	10.0	4.52	62.82	13.77	145.08	56.79	88.290	0.971	8.300	1036	8349.43	896
I	47	2.48	5.0	2.02	59.90	13.80	139.82	56.84	82.980	0.966	3.780	1036	3782.93	896
I	48	2.56	5.0	1.95	59.16	14.32	138.49	57.78	80.712	0.966	3.635	1036	3637.82	896
I	49	2.34	10.0	4.28	61.08	13.50	141.94	56.30	85.644	0.967	7.980	1036	7994.46	896
I	50	2.38	5.0	2.10	61.15	13.45	142.07	56.21	85.860	0.967	3.940	1036	3947.14	896
I	68	1.59	21.4	13.45	49.82	21.29	121.68	70.32	51.354	0.972	11.035	1036	11112.16	896
I	69	2.17	21.4	9.85	70.45	21.20	158.81	70.16	88.650	0.969	18.630	1036	18702.36	896
I	70	2.57	21.4	8.32	64.24	21.18	147.63	70.12	77.517	0.969	16.380	1036	16443.62	896
I	71	2.97	21.4	7.20	58.68	21.16	137.62	70.09	67.536	0.968	14.165	1036	14205.34	896
I	72	2.99	21.4	7.17	58.26	21.04	136.87	69.87	66.996	0.967	14.145	1033	14129.60	896
I	73	2.99	21.4	7.17	59.14	21.43	138.45	70.57	67.878	0.968	14.240	1033	14239.20	896
I	74	2.96	21.4	7.23	59.44	21.61	138.99	70.90	68.094	0.965	14.290	1033	14244.92	896
I	75	2.06	21.4	10.38	70.49	21.51	158.88	70.72	88.164	0.966	18.750	1033	18710.21	896
I	76	1.50	21.4	14.27	49.38	21.18	120.88	70.12	50.760	0.969	10.860	1033	10870.61	896
I	77	3.01	21.4	7.10	57.36	20.75	135.25	69.35	65.898	0.966	13.820	1033	13790.67	896
I	78	2.99	21.4	7.17	65.40	20.44	149.72	68.79	80.928	0.963	17.020	1033	16931.14	896
I	97	1.62	21.4	13.22	50.98	20.99	123.76	69.78	53.982	0.980	11.305	1038	11499.90	896
I	98	2.09	21.4	10.23	65.82	20.55	150.48	68.99	81.486	0.980	16.275	1038	16555.58	896
I	99	2.52	21.4	8.50	64.90	21.10	148.82	69.98	78.840	0.975	16.290	1038	16486.29	896
I	100	2.97	21.4	7.20	59.24	21.11	138.63	70.00	68.634	0.973	14.015	1038	14154.79	896
I	119	1.63	21.4	13.13	51.47	22.14	124.65	71.85	52.794	0.974	11.480	1036	11584.05	896
I	120	2.19	21.4	9.77	70.52	21.91	158.94	71.44	87.498	0.970	18.642	1036	18733.72	896
I	121	2.66	21.4	8.05	63.53	21.81	146.35	71.26	75.096	0.970	15.930	1036	16008.38	896
I	122	2.81	21.4	7.62	61.14	21.83	142.05	71.29	70.758	0.970	14.860	1036	14933.11	896

* = Measured Data

Table 2a. Summary Data, Er, and EF - Unit F

SUMMARY - UNIT F

UNIT	TEST	FLOW (Gpm)	AMT (Gal)	T(F) (Out)	T(F) (In)	T(F) (Delta T)	Er	EF (20 Gpd)	EF (40 Gpd)	EF (64.3 Gpd)	EF (80 Gpd)	PILOT (BTU/ Hr)
F	2	2.15	15.0	126.8	72.3	54.5	0.746	0.446	0.559	0.618	0.640	340
F	3	2.25	15.0	123.9	72.2	51.7	0.790	0.451	0.575	0.642	0.667	340
F	4	2.31	15.0	123.4	71.5	51.9	0.799	0.455	0.581	0.648	0.674	340
F	5	1.07	15.0	135.9	70.0	65.9	0.764	0.488	0.597	0.652	0.672	340
F	7	1.07	15.0	137.1	69.2	67.9	0.763	0.493	0.601	0.655	0.674	340
F	8	3.19	15.0	114.2	71.9	42.3	0.819	0.419	0.556	0.633	0.663	340
F	9	3.24	15.0	115.9	71.1	44.8	0.820	0.431	0.566	0.642	0.671	340
F	10	1.00	5.0	112.9	70.5	42.4	0.871	0.435	0.583	0.669	0.703	340
F	11	3.62	5.0	113.5	70.1	43.4	0.856	0.434	0.577	0.659	0.690	340
F	12	3.49	10.0	114.5	69.6	44.8	0.851	0.440	0.581	0.660	0.691	340
F	13	3.33	10.0	116.6	72.1	44.5	0.825	0.431	0.567	0.644	0.673	340
F	51	0.93	5.0	146.2	57.9	88.3	0.790	0.550	0.650	0.698	0.715	340
F	52	0.78	10.0	145.2	59.0	86.2	0.769	0.536	0.634	0.681	0.697	340
F	53	0.95	21.4	136.4	74.1	62.3	0.759	0.476	0.587	0.644	0.665	340
F	54	1.53	21.4	129.2	73.8	55.4	0.793	0.466	0.589	0.653	0.678	340
F	55	1.95	21.4	125.9	72.5	53.4	0.810	0.464	0.591	0.660	0.685	340
F	56	2.62	21.4	118.6	71.7	46.9	0.828	0.443	0.578	0.653	0.682	340
F	57	3.11	21.4	114.2	71.2	43.0	0.831	0.426	0.564	0.643	0.673	340
F	87	0.98	21.4	138.3	70.6	67.7	0.728	0.478	0.578	0.629	0.647	340
F	88	1.55	21.4	131.3	69.9	61.4	0.750	0.469	0.579	0.634	0.655	340
F	89	2.10	21.4	124.4	70.6	53.8	0.763	0.450	0.567	0.629	0.652	340
F	90	2.53	21.4	119.5	70.1	49.4	0.782	0.440	0.564	0.631	0.657	340
F	91	3.08	21.4	116.1	68.5	47.6	0.784	0.433	0.559	0.628	0.654	340
F	101	1.08	21.4	136.3	69.7	66.6	0.723	0.472	0.573	0.623	0.641	340
F	102	1.65	21.4	130.2	70.1	60.1	0.749	0.465	0.575	0.631	0.652	340
F	103	2.12	21.4	125.8	70.4	55.4	0.761	0.455	0.570	0.631	0.653	340
F	104	2.63	21.4	119.0	70.6	48.3	0.774	0.433	0.556	0.623	0.648	340
F	105	2.99	21.4	115.8	71.0	44.8	0.777	0.419	0.545	0.615	0.642	340

Table 2b. Summary Data, Er, and EF - Unit G

SUMMARY - UNIT G

UNIT	TEST	FLOW (Gpm)	AMT (Gal)	T(F) (Out)	T(F) (In)	T(F) (Delta T)	Er	EF (20 Gpd)	EF (40 Gpd)	EF (64.3 Gpd)	EF (80 Gpd)	PILOT (BTU/ Hr)
G	29	2.22	5.0	134.5	69.4	65.1	0.783	0.483	0.599	0.658	0.680	357
G	30	2.11	5.0	139.9	69.8	70.1	0.800	0.503	0.619	0.678	0.699	357
G	31	2.07	5.0	140.4	70.0	70.5	0.793	0.502	0.615	0.673	0.694	357
G	32	1.63	5.0	153.5	70.2	83.3	0.784	0.528	0.632	0.683	0.701	357
G	58	1.01	21.4	142.7	71.0	71.7	0.780	0.501	0.612	0.668	0.688	357
G	59	1.65	21.4	156.2	70.8	85.4	0.824	0.550	0.661	0.715	0.735	357
G	60	2.10	21.4	140.8	70.8	70.0	0.828	0.514	0.636	0.698	0.720	357
G	61	2.53	21.4	129.4	70.8	58.6	0.833	0.480	0.610	0.680	0.706	357
G	62	3.16	21.4	117.2	70.7	46.5	0.833	0.433	0.570	0.648	0.678	357
G	79	1.06	21.4	145.2	70.6	74.6	0.762	0.500	0.605	0.658	0.677	357
G	80	1.65	21.4	152.4	69.6	82.8	0.786	0.528	0.633	0.684	0.703	357
G	81	2.10	21.4	139.6	70.2	69.5	0.794	0.500	0.614	0.673	0.694	357
G	82	2.68	21.4	124.8	69.9	54.9	0.774	0.448	0.568	0.632	0.656	357
G	83	2.68	21.4	124.1	69.4	54.8	0.775	0.448	0.568	0.633	0.657	357
G	84	2.66	50.0	123.6	68.3	55.3	0.779	0.451	0.572	0.637	0.661	357
G	85	2.63	50.0	123.2	67.4	55.8	0.781	0.453	0.574	0.639	0.663	357
G	86	3.02	21.4	120.0	70.8	49.2	0.784	0.430	0.556	0.625	0.652	357
G	106	1.06	21.4	144.6	71.4	73.2	0.737	0.486	0.588	0.638	0.656	357
G	107	1.35	21.4	143.7	71.9	71.7	0.750	0.488	0.592	0.645	0.663	357
G	108	1.63	21.4	152.5	72.2	80.3	0.770	0.516	0.619	0.669	0.687	357
G	109	1.87	21.4	150.7	72.4	78.4	0.786	0.518	0.625	0.678	0.698	357
G	110	2.08	21.4	142.8	72.6	70.2	0.781	0.496	0.608	0.664	0.685	357
G	111	2.64	21.4	128.0	72.7	55.3	0.782	0.452	0.574	0.639	0.663	357
G	112	3.16	21.4	119.5	72.7	46.9	0.790	0.422	0.551	0.623	0.650	357

Table 2c. Summary Data, Er, and EF - Unit H

SUMMARY - UNIT H

UNIT	TEST	FLOW (Gpm)	AMT (Gal)	T(F) (Out)	T(F) (In)	T(F) (Delta T)	Er	EF (20 Gpd)	EF (40 Gpd)	EF (64.3 Gpd)	EF (80 Gpd)	PILOT (BTU/ Hr)
H	14	1.28	5.0	154.3	70.7	83.6	0.752	0.410	0.533	0.600	0.626	643
H	15	1.36	5.0	154.4	70.7	83.7	0.753	0.411	0.533	0.601	0.627	643
H	16	3.86	14.2	117.5	70.7	46.8	0.796	0.308	0.445	0.535	0.572	643
H	17	3.84	14.1	116.6	70.5	46.1	0.782	0.303	0.437	0.525	0.562	643
H	18	1.83	5.0	148.2	70.5	77.7	0.770	0.401	0.529	0.601	0.629	643
H	19	1.78	5.0	148.1	70.5	77.6	0.780	0.404	0.533	0.607	0.636	643
H	20	4.07	11.3	114.5	70.6	44.0	0.803	0.297	0.435	0.527	0.565	643
H	21	3.99	11.1	116.1	70.5	45.5	0.807	0.304	0.443	0.534	0.573	643
H	22	2.34	5.0	141.0	71.2	69.8	0.783	0.383	0.516	0.593	0.624	643
H	23	2.38	5.0	141.2	71.1	70.1	0.797	0.387	0.523	0.602	0.633	643
H	24	1.37	5.0	153.2	71.0	82.2	0.739	0.403	0.524	0.590	0.615	643
H	25	1.59	5.0	150.6	70.8	79.7	0.766	0.405	0.531	0.602	0.629	643
H	26	3.00	5.0	126.7	70.5	56.3	0.798	0.344	0.482	0.567	0.602	643
H	27	2.08	5.0	144.0	70.2	73.8	0.786	0.395	0.527	0.603	0.633	643
H	28	3.49	5.0	119.4	69.9	49.5	0.801	0.319	0.458	0.547	0.584	643
H	40	2.21	7.5	136.9	58.1	78.9	0.801	0.412	0.545	0.621	0.651	643
H	41	2.21	7.5	135.6	58.3	77.3	0.802	0.408	0.542	0.619	0.648	643
H	42	1.10	7.5	135.1	59.4	75.7	0.758	0.394	0.520	0.592	0.620	643
H	43	1.04	7.5	140.6	60.6	80.0	0.744	0.401	0.523	0.591	0.617	643
H	44	1.01	7.5	142.5	56.0	86.5	0.756	0.419	0.541	0.608	0.634	643
H	45	1.61	7.5	142.1	56.8	85.3	0.803	0.429	0.560	0.634	0.662	643
H	46	2.30	7.5	141.3	55.6	85.7	0.830	0.437	0.574	0.651	0.680	643
H	63	1.05	21.4	156.2	72.1	84.1	0.756	0.413	0.537	0.605	0.631	643
H	64	1.65	21.4	144.1	71.9	72.3	0.767	0.387	0.516	0.590	0.619	643
H	65	2.05	21.4	142.9	71.0	71.9	0.802	0.394	0.530	0.609	0.640	643
H	66	2.53	21.4	136.2	70.9	65.3	0.819	0.378	0.518	0.603	0.636	643
H	67	3.13	21.4	127.1	70.6	56.5	0.837	0.352	0.496	0.588	0.625	643
H	92	1.04	21.4	161.2	70.3	90.9	0.723	0.417	0.531	0.592	0.615	643
H	93	1.64	21.4	151.6	70.4	81.2	0.756	0.406	0.529	0.598	0.625	643
H	94	2.13	21.4	144.3	69.4	74.8	0.772	0.394	0.523	0.597	0.625	643
H	95	2.55	21.4	137.8	70.0	67.8	0.785	0.378	0.511	0.590	0.621	643
H	96	3.17	21.4	125.6	70.3	55.3	0.791	0.339	0.476	0.561	0.596	643
H	113	1.05	21.4	160.1	72.7	87.4	0.721	0.409	0.524	0.586	0.610	643
H	114	1.68	21.4	149.5	72.7	76.8	0.750	0.394	0.518	0.588	0.615	643
H	115	1.33	21.4	154.5	72.7	81.8	0.733	0.401	0.520	0.585	0.610	643
H	116	2.09	21.0	145.5	71.8	73.8	0.748	0.385	0.510	0.581	0.608	643
H	117	2.64	21.4	135.4	72.2	63.2	0.759	0.359	0.488	0.565	0.595	643
H	118	3.06	21.4	128.1	72.5	55.6	0.765	0.335	0.467	0.548	0.581	643

Table 2d. Summary Data, Er, and EF - Unit I

SUMMARY - UNIT I

UNIT	TEST	FLOW (Gpm)	AMT (Gal)	T(F) (Out)	T(F) (In)	T(F) (Delta T)	Er	EF (20 Gpd)	EF (40 Gpd)	EF (64.3 Gpd)	EF (80 Gpd)	PILOT (BTU/ Hr)
I	33	2.37	10.0	153.8	70.9	82.9	0.875	0.369	0.521	0.616	0.655	896
I	34	2.50	10.0	149.0	70.9	78.1	0.849	0.353	0.499	0.593	0.631	896
I	35	2.15	10.0	158.1	70.6	87.4	0.855	0.377	0.525	0.616	0.653	896
I	36	2.25	10.0	154.8	70.3	84.5	0.866	0.372	0.522	0.615	0.653	896
I	37	2.66	10.0	130.9	54.9	76.0	0.867	0.350	0.499	0.596	0.636	896
I	38	2.66	10.0	130.7	55.5	75.2	0.865	0.347	0.497	0.593	0.633	896
I	39	2.21	10.0	145.1	56.8	88.3	0.872	0.383	0.533	0.627	0.664	896
I	47	2.48	5.0	139.8	56.8	83.0	0.905	0.375	0.531	0.631	0.672	896
I	48	2.56	5.0	138.5	57.8	80.7	0.915	0.371	0.529	0.630	0.672	896
I	49	2.34	10.0	141.9	56.3	85.6	0.884	0.378	0.531	0.627	0.665	896
I	50	2.38	5.0	142.1	56.2	85.9	0.897	0.381	0.536	0.634	0.673	896
I	68	1.59	21.4	121.7	70.3	51.4	0.816	0.267	0.404	0.502	0.544	896
I	69	2.17	21.4	158.8	70.2	88.7	0.837	0.377	0.521	0.609	0.644	896
I	70	2.57	21.4	147.6	70.1	77.5	0.832	0.348	0.492	0.583	0.620	896
I	71	2.97	21.4	137.6	70.1	67.5	0.839	0.321	0.466	0.561	0.601	896
I	72	2.99	21.4	136.9	69.9	67.0	0.837	0.319	0.463	0.558	0.598	896
I	73	2.99	21.4	138.5	70.6	67.9	0.842	0.323	0.467	0.563	0.603	896
I	74	2.96	21.4	139.0	70.9	68.1	0.844	0.324	0.469	0.565	0.604	896
I	75	2.06	21.4	158.9	70.7	88.2	0.832	0.374	0.518	0.605	0.640	896
I	76	1.50	21.4	120.9	70.1	50.8	0.824	0.266	0.404	0.503	0.546	896
I	77	3.01	21.4	135.2	69.4	65.9	0.844	0.317	0.462	0.558	0.599	896
I	78	2.99	21.4	149.7	68.8	80.9	0.844	0.359	0.504	0.596	0.633	896
I	97	1.62	21.4	123.8	69.8	54.0	0.829	0.278	0.418	0.516	0.559	896
I	98	2.09	21.4	150.5	69.0	81.5	0.869	0.365	0.516	0.611	0.649	896
I	99	2.52	21.4	148.8	70.0	78.8	0.844	0.354	0.500	0.592	0.629	896
I	100	2.97	21.4	138.6	70.0	68.6	0.856	0.327	0.474	0.571	0.612	896
I	119	1.63	21.4	124.6	71.9	52.8	0.805	0.271	0.407	0.503	0.544	896
I	120	2.19	21.4	158.9	71.4	87.5	0.825	0.371	0.513	0.600	0.635	896
I	121	2.66	21.4	146.4	71.3	75.1	0.828	0.341	0.484	0.575	0.613	896
I	122	2.81	21.4	142.1	71.3	70.8	0.837	0.330	0.475	0.568	0.607	896

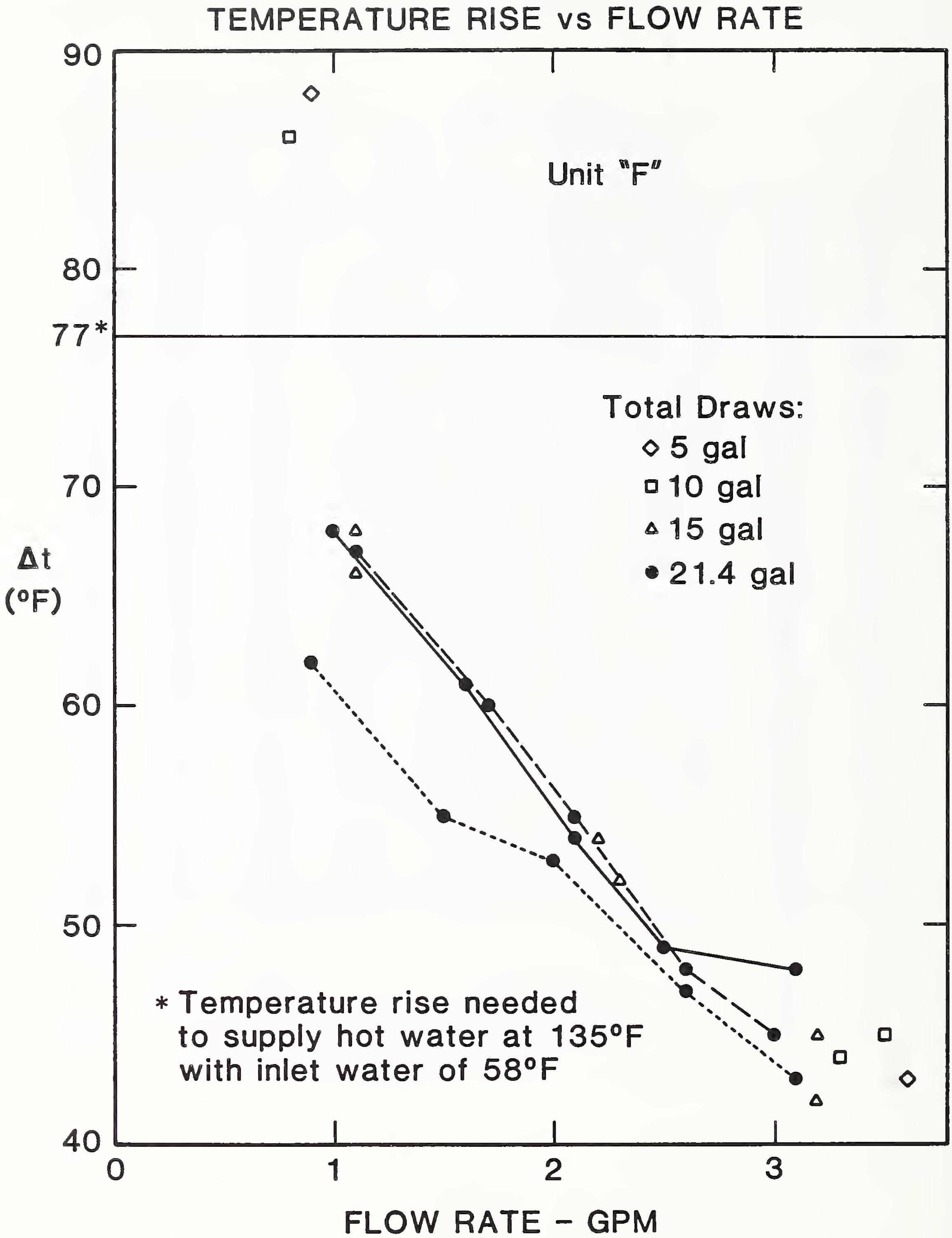


Figure 2. Temperature Rise vs. Flow Rate - Unit F.

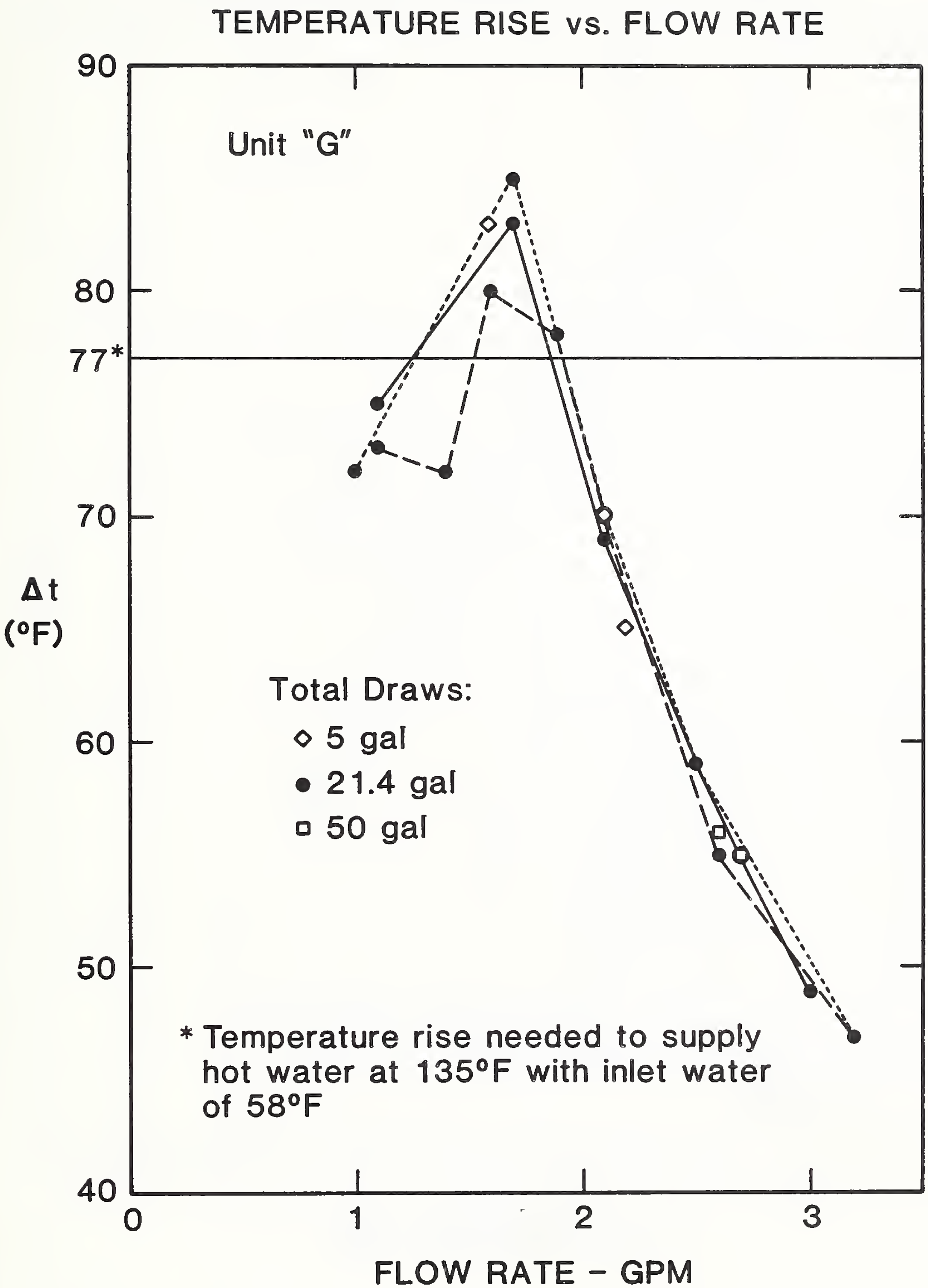


Figure 3. Temperature Rise vs. Flow Rate - Unit G.

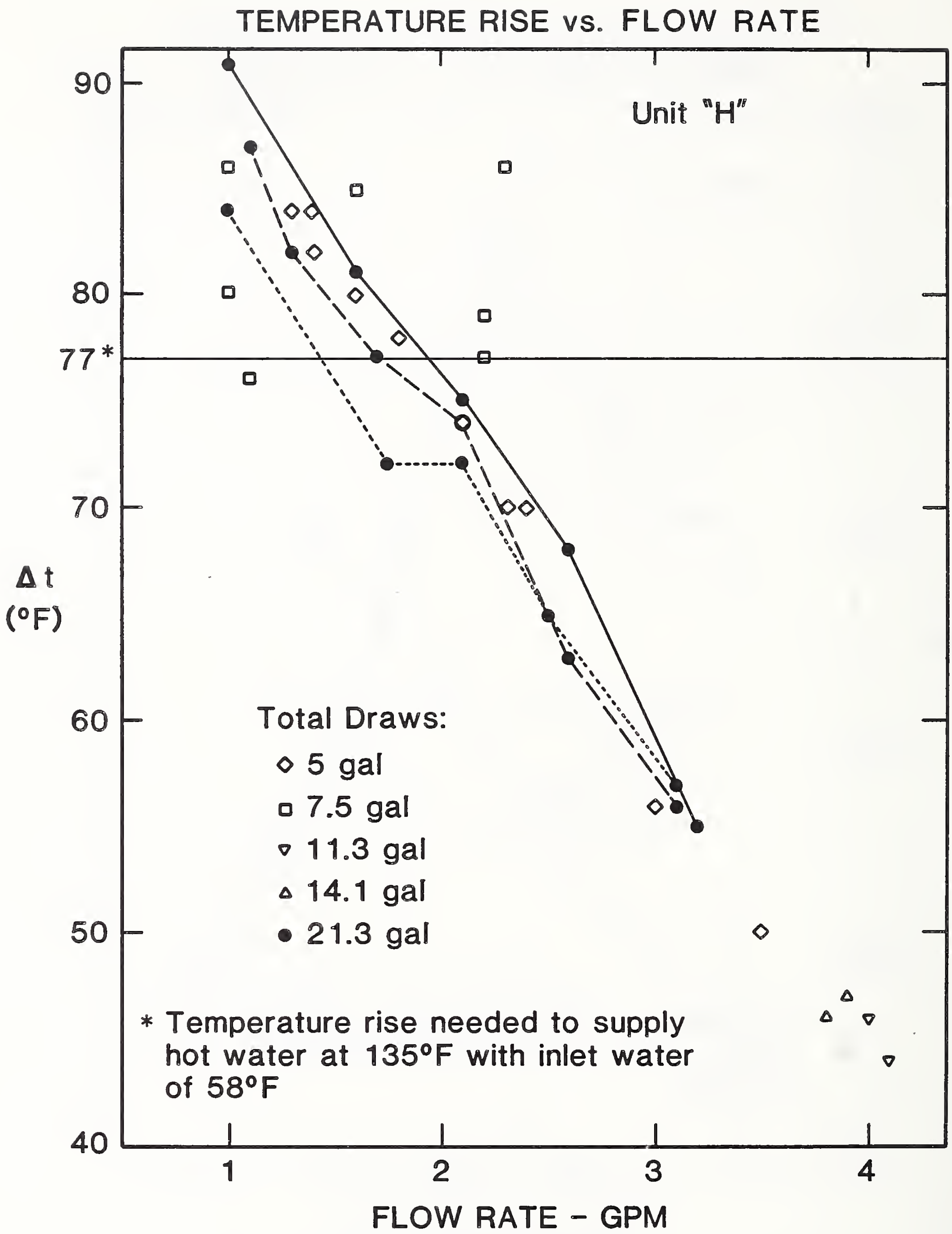


Figure 4. Temperature Rise vs. Flow Rate - Unit H.

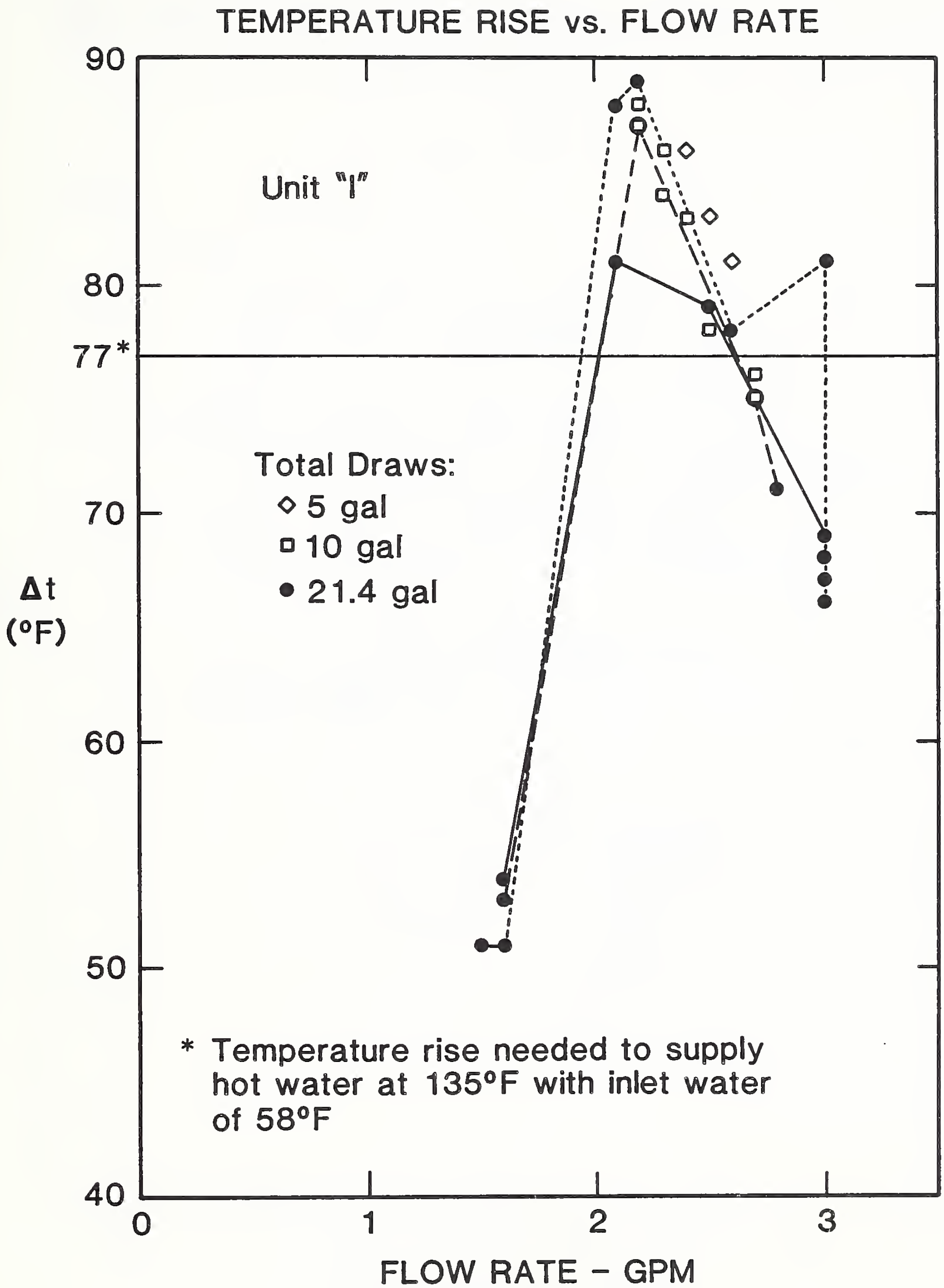


Figure 5. Temperature Rise vs. Flow Rate - Unit I.

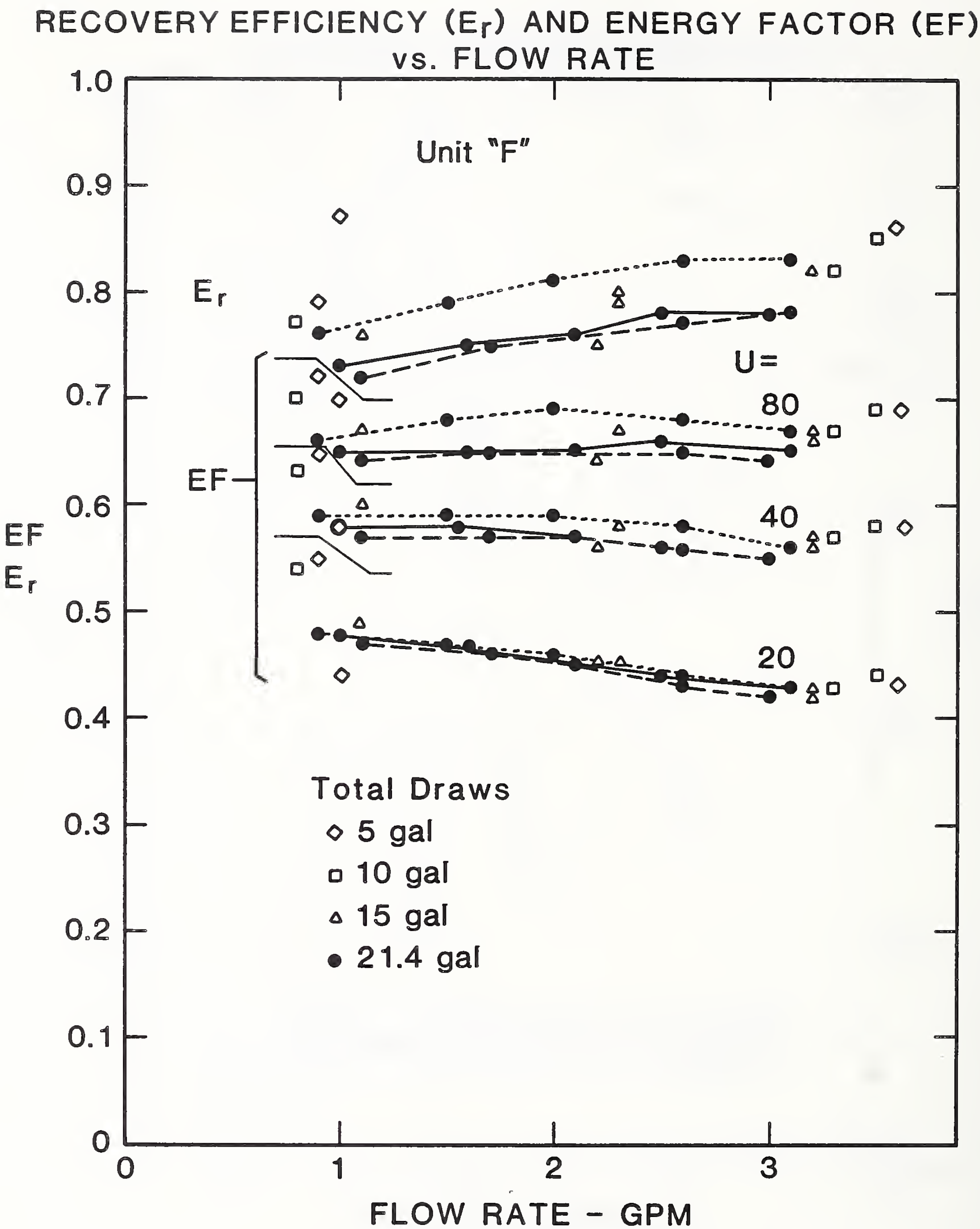


Figure 6. Recovery Efficiency (Er) and Energy Factor (EF) vs. Flow Rate - Unit F.

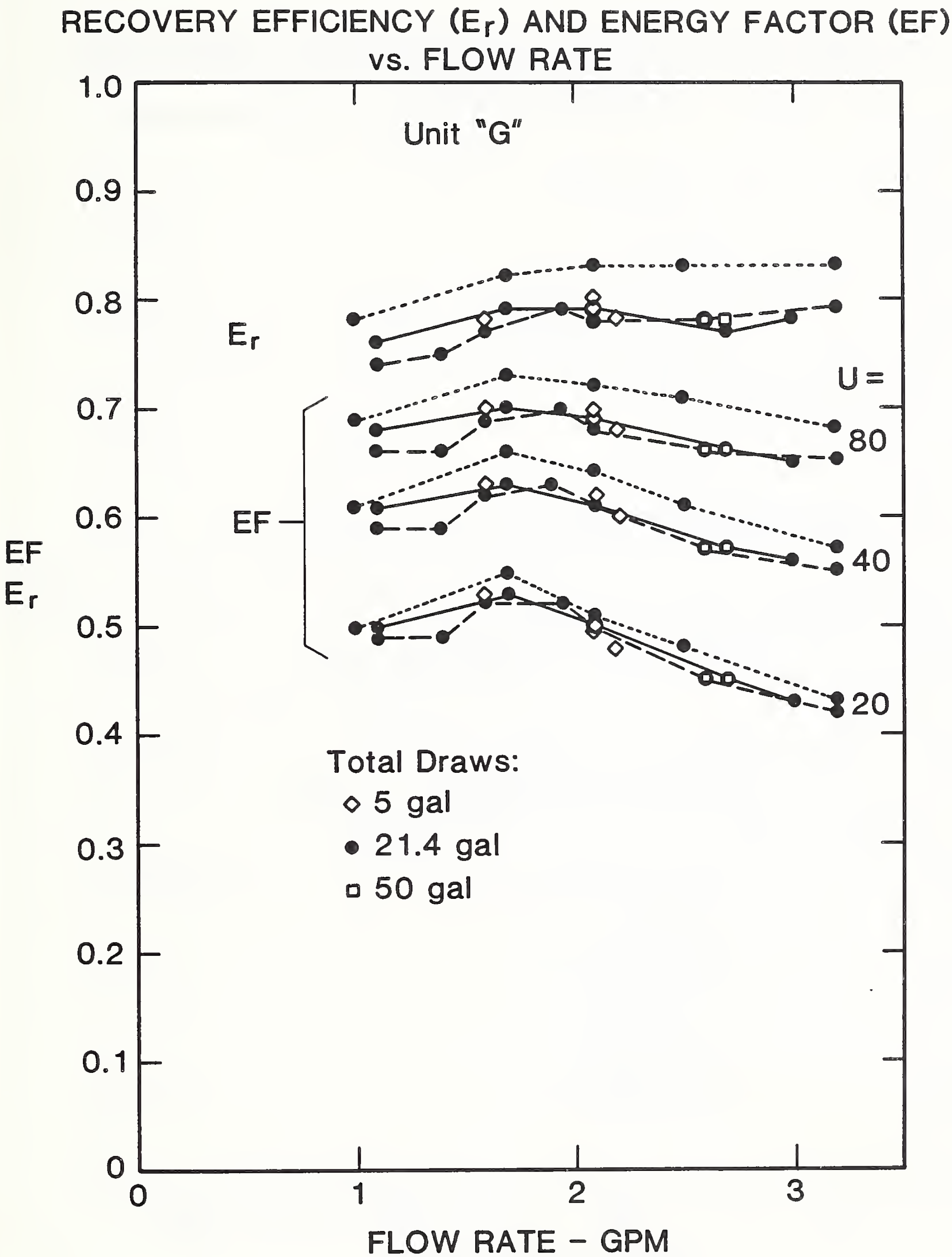


Figure 7. Recovery Efficiency (Er) and Energy Factor (EF) vs. Flow Rate - Unit G.

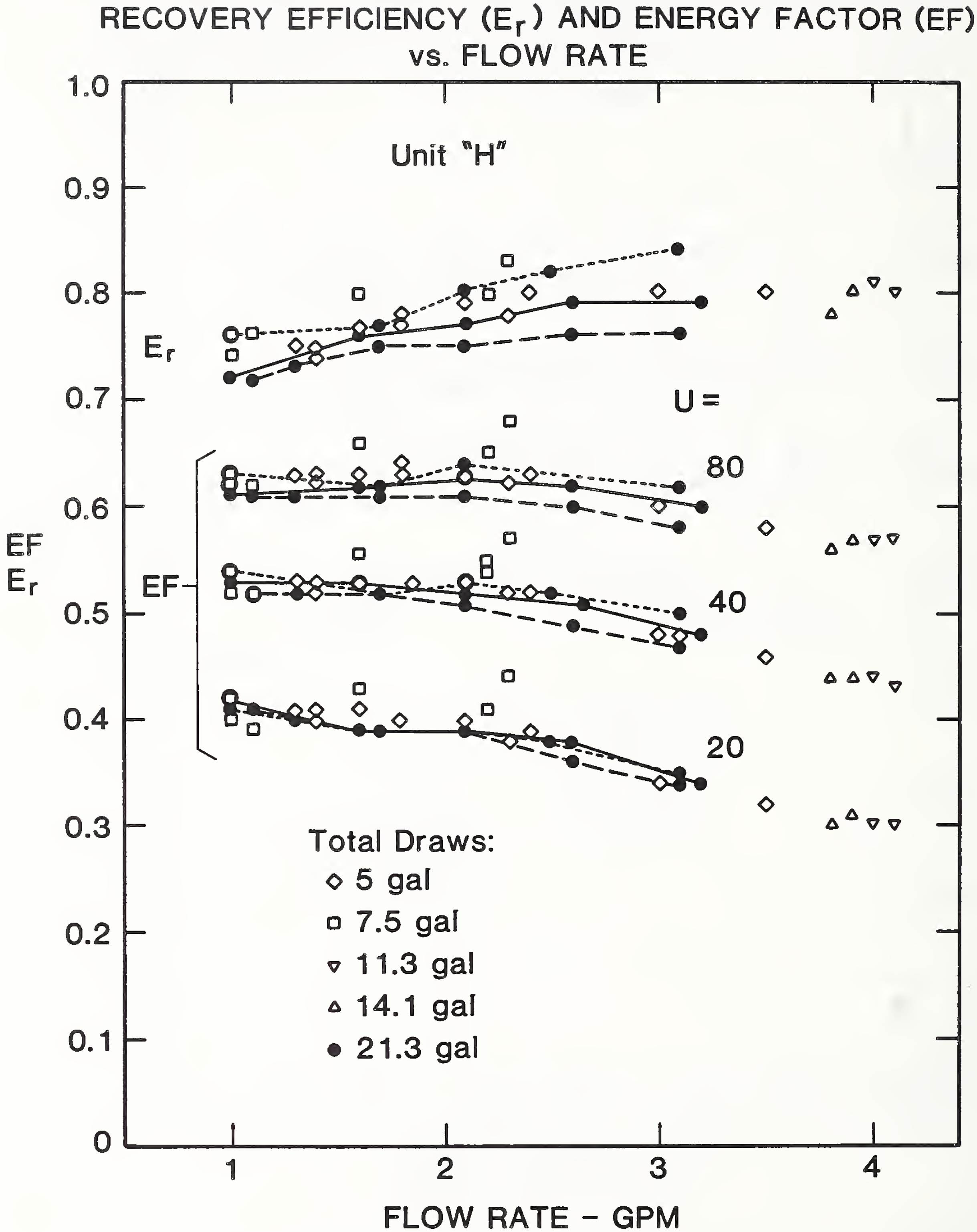


Figure 8. Recovery Efficiency (Er) and Energy Factor (EF) vs. Flow Rate - Unit H.

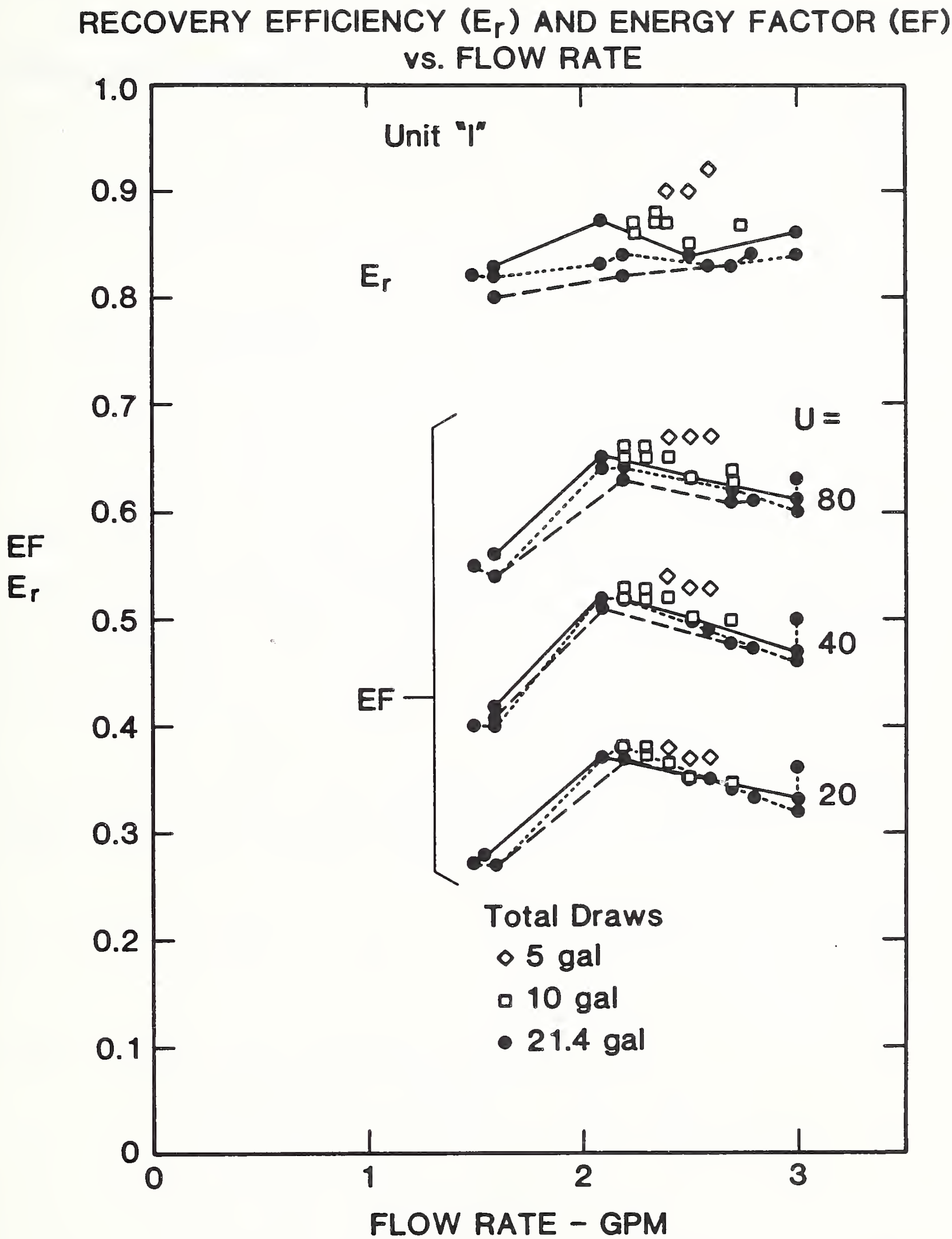


Figure 9. Recovery Efficiency (Er) and Energy Factor (EF) vs. Flow Rate - Unit I.

Appendix A

COMPUTATIONS AND FORMULAS USED

In order to compute an energy factor to determine the annual cost of operation of an instantaneous gas-fired water heater, the following formulas are used in the order presented.

1.0 Gas Correction Factor

The correction factor, Cf, to determine the "standard" gas volume used was determined using equation (1) where "standard" conditions are at 60°F and 30.00 inches Hg (1016 millibars) atmospheric pressure. The partial pressure of the water vapor was determined from tables of vapor pressure of water at various temperatures, by entering the appropriate gas temperature. The other pressures were taken from appropriate instrument readings.

The correction factor, Cf, (dimensionless) to determine standard gas volume used during a gas water heater test and is defined as:

$$Cf = (17.64)(Pg+Pa-Pwv)/(Tg+460) \qquad \text{(dimensionless)} \qquad (1)$$

where: Pg is the gas pressure* (inches Hg);

Pa is the atmospheric pressure* (inches Hg);

Pwv is the water vapor pressure, partial (inches Hg);

Tg is the temperature of gas (°F).

*NOTE: to convert inches of water to inches Hg, multiply by 0.07343; to convert millibars to inches Hg, multiply by 0.02953.

2.0 Energy Used During a Test

The energy used during a test was determined by equation (2) where the volume, Vol, of gas used during a test is corrected to standard conditions using Cf and is converted to Btu using the higher heating value of the gas.

The energy used during a test is defined as:

$$Q = (Cf)(H)(Vol) \qquad \text{(Btu)} \qquad (2)$$

where: Cf is the correction factor as defined in 1.0;

H is the higher heating value of gas used (Btu per SCF);

Vol is the volume of gas used during a test as measured by the gas meter (cubic feet).

3.0 Mean Outlet Hot Water Temperature

The mean value of the outlet hot water temperature, expressed in degrees F, was determined by equation (4) and is defined as:

$$Twout = T1+T2+...Tn/n \qquad \text{(F)} \qquad (4)$$

where: T1 is the hot water temperature at the end of the first minute of the draw (°F);

T2 is the hot water temperature at the end of the second minute of the draw (°F);

Tn is the hot water temperature at the start of the nth minute of the draw (°F);

n is the number of outlet hot water temperature measurements.

4.0 Mean Supply Water Temperature

The mean value of the supply (cold) water temperature, expressed in degrees F, was determined by equation (5) and is defined as:

$$Twin = T1 + T2 + \ldots Tn/n \qquad (F) \qquad (5)$$

where: T1 is the cold water inlet temperature at the end of the first minute of the draw (°F);

T2 is the cold water inlet temperature at the end of the second minute of the draw (°F);

Tn is the cold water inlet temperature at the end of the nth minute of the draw (°F);

n is the number of supply water temperature measurements.

5.0 Recovery Efficiency

The recovery efficiency during a test was determined by equation (3) and is defined as:

$$Er = (k)(V)(T1)/(Q) \qquad \text{(dimensionless)} \qquad (3)$$

where: k is the nominal specific heat of water during the temperature ranges used (8.25 Btu/gallon °F);

V is the volume of the water draw during the test (U.S. gallons);

T1 is the mean temperature rise (°F) of the hot water drawn during test and is equal to (Twout-Twin);

(Twout) is defined in 3.0;

(Twin) is defined in 4.0;

Q is defined in 2.0.

6.0 Daily Water Heating Energy Consumption

The daily water heating energy consumption, expressed in Btu per day and using an established daily hot water usage of 64.3 gallons was determined by equation (6) and is defined as:

$$Cwh = (k)(U)(Tl)/(Er) \qquad \text{(Btu/day)} \qquad (6)$$

where: k, Tl and Er are defined in 5.0;

U is the established daily hot water usage, 64.3 gallons.

NOTE: When the value of U differs from 64.3 gallons, the actual measured gallons is used for the computations.

The actual hot water temperature rise (Tl) is used instead of an assumed or fixed value because the power input rate for most instantaneous gas-fired water heaters is variable. In addition, the actual temperature rise of the water is variable and it may differ significantly from any fixed or assumed value.

7.0 The Flow Rate During a Draw

The flow rate of hot water during a draw was determined by equation (7) by weighing the water from a draw and timing the draw. The flow rate is defined as:

$$Fr = Ww/((Td)(8.25)) \qquad \text{(gal/min)} \qquad (7)$$

where: Ww is the weight of the water during the draw in pounds;

Td is the duration of the draw in minutes;

8.25 is a constant to convert pounds of water to gallons of water.

8.0 Power (Firing Rate) Determination

The average power, in Btu/hour, input for a given test was determined by equation (8) and is defined as:

$$P = (60\ \text{min/hour})(Q)/(Tb) \qquad (\text{Btu/hour}) \qquad (8)$$

where: Q is defined in 2.0;

Tb is the duration of the burner on time in minutes;

60 is a constant to convert minutes to hours.

9.0 Daily Hot Water Energy Consumption

The daily hot water energy consumption was determined by equation (9) and is defined as:

$$Cc = (k)(U)(Tl) \qquad (\text{Btu/day}) \qquad (9)$$

where: k and Tl are defined in 5.0;

U is defined in 6.0.

10.0 Pilot Light Energy Consumption Rate

The pilot light energy consumption rate was measured for each unit. These tests were conducted by measuring the volume of gas used by the pilot light (Vol), correcting to a standard conditions by equation (1) in 1.0 by determining the value of Cf and measuring the duration of the

pilot light energy consumption rate was then determined by equation (10) and is defined as:

$$Pr = (Vol)(Cf)(H)/(Tp) \qquad \text{(Btu/hour)} \qquad (10)$$

where: Vol is the cubic feet of gas measured by the gas meter during the pilot light test expressed in cubic feet;

Cf is defined in 1.0;

H is defined in 2.0;

Tp is the duration of the pilot light test in hours (nominally 22 hours).

11.0 Average Daily Energy Consumption

The average daily energy consumption was determined by equation (11) and is defined as:

$$Cy = Cwh+(Pr)(24-(U)/((60)(Fr))) \qquad \text{(Btu/day)} \qquad (11)$$

where: Cwh and U are defined in 6.0;

Pr is defined in 10.0;

Fr is defined in 7.0;

60 is a constant to convert minutes to hours and 24 is the hours per day.

12.0 Energy Factor

The energy factor was determined by equation (12) and is defined as:

$$EF = (Cc)/(Cy) \qquad \text{(dimensionless)} \qquad (12)$$

where: (Cc) is defined in 9.0;

(Cy) is defined in 11.0.

Appendix B

UNITS CONVERSION TABLE: SI/INCH-POUND/SI

TO CONVERT	MULTIPLY BY	TO OBTAIN
gpm (Gallons/minute)	0.06309	L/s (Liters/second)
L/s (Liters/second)	15.85	gpm (Gallons/minute)
g (Gallons)	3.785	L (Liters)
L (Liters)	0.2642	g (Gallons)
in (Inches)	2.54	cm (Centimeters)
cm (Centimeters)	0.3937	in (Inches)
ft (Feet)	0.3048	m (Meters)
m (Meters)	3.281	ft (Feet)
BTU (British Thermal Units)	1.055	kJ (Kilojoules)
kJ (Kilojoules)	0.9479	BTU (British Thermal Units)

TEMPERATURE (T), CONVERSION EQUATIONS:

For Temperature Use:

°F to °C: $[(T)°F - 32°F](5/9) = (T)°C$

°C to °F: $[(T)°C(9/5) + 32°F = (T)°F$

FOR TEMPERATURE DIFFERENTIALS OR TOLERANCES USE:

°F to °C: $(T)°F(5/9) = (T)°C$

°C to °F: $(T)°C(9/5) = (T)°F$

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Four different instantaneous, gas-fired water heaters were tested to develop a test method to determine recovery efficiency (Er) and energy factor (EF). All four of the water heaters were from foreign countries (West Germany, the United Kingdom, France and Japan). Various flow rates and water draws were used during the tests to determine their influence on the recovery efficiency and energy factor. In addition, the pilot light power consumption was measured to determine the effect of a variable pilot light power rate on the energy factor. The use of recovery efficiency as a performance index seems appropriate for these units, however, the use of energy factor as presently calculated, needs further study.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

appliance standards; energy conservation; geyser; instantaneous water heaters; in-line water heaters; tankless water heaters

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